

## CHAPTER 1

### INTRODUCTION

#### 1-1. Purpose

This manual provides guidance for designing reinforced-concrete hydraulic structures by the strength-design method.

#### 1-2. Applicability

This manual applies to all HQUSACE/OCE elements, major subordinate commands, districts, laboratories, and field operating activities having civil works responsibilities.

#### 1-3. References

- a. EM 1110-1-2101, Working Stresses for Structural Design.
- b. EM 1110-2-2902, Conduits, Culverts, and Pipes.
- c. CW-03210, Civil Works Construction Guide Specification for Steel Bars, Welded Wire Fabric, and Accessories for Concrete Reinforcement.
- d. American Concrete Institute, "Building Code Requirements and Commentary for Reinforced Concrete," ACI 318, Box 19150, Redford Station, Detroit, MI 48219.
- e. American Concrete Institute, "Environmental Engineering Concrete Structures," ACI 350R, Box 19150, Redford Station, Detroit, MI 48219.
- f. American Society for Testing and Materials, "Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement," ASTM A 615-89, 1916 Race St., Philadelphia, PA 19103.
- g. American Welding Society, "Structural Welding Code-Reinforcing Steel," AWS D1.4-790, 550 NW Le Jeune Rd., P.O. Box 351040, Miami, FL 33135.
- h. Liu, Tony C. 1980 (Jul). "Strength Design of Reinforced Concrete Hydraulic Structures, Report 1: Preliminary Strength Design Criteria," Technical Report SL-80-4, US Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180.
- i. Liu, Tony C., and Gleason, Scott. 1981 (Sep). "Strength Design of Reinforced Concrete Hydraulic Structures, Report 2: Design Aids for Use in the Design and Analysis of Reinforced Concrete Hydraulic Structural Members Subjected to Combined Flexural and Axial Loads," Technical Report SL-80-4, US Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180.

j. Liu, Tony C. 1981 (Sep). "Strength Design of Reinforced Concrete Hydraulic Structures, Report 3: T-Wall Design," Technical Report SL-80-4, US Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180.

#### 1-4. Background

a. A reinforced concrete hydraulic structure is one that will be subjected to one or more of the following: submergence, wave action, spray, chemically contaminated atmosphere, and severe climatic conditions. Typical hydraulic structures are stilling-basin slabs and walls, concrete-lined channels, portions of powerhouses, spillway piers, spray walls and training walls, floodwalls, intake and outlet structures below maximum high water and wave action, lock walls, guide and guard walls, and retaining walls subject to contact with water.

b. In general, existing reinforced-concrete hydraulic structures designed by the Corps, using the working stress method of EM 1110-1-2101, have held up extremely well. The Corps began using strength design methods in 1981 (Liu 1980, 1981 and Liu and Gleason 1981) to stay in step with industry, universities, and other engineering organizations. ETL 1110-2-265, "Strength Design Criteria for Reinforced Concrete Hydraulic Structures," dated 15 September 1981, was the first document providing guidance issued by the Corps concerning the use of strength design methods for hydraulic structures. The labor-intensive requirements of this ETL regarding the application of multiple load factors, as well as the fact that some load-factor combination conditions resulted in a less conservative design than if working stress methods were used, resulted in the development of ETL 1110-2-312, "Strength Design Criteria for Reinforced Concrete Hydraulic Structures," dated 10 March 1988.

c. The revised load factors in ETL 1110-2-312 were intended to ensure that the resulting design was as conservative as if working stress methods were used. Also, the single load factor concept was introduced. The guidance in this ETL differed from ACI 318 Building Code Requirements and Commentary for Reinforced Concrete primarily in the load factors, the concrete stress-strain relationship, and the yield strength of Grade 60 reinforcement. ETL 1110-2-312 guidance was intended to result in designs equivalent to those resulting when working stress methods were used.

d. Earlier Corps strength design methods deviated from ACI guidance because ACI 318 includes no provisions for the serviceability needs of hydraulic structures. Strength and stability are required, but serviceability in terms of deflections, cracking, and durability demand equal consideration. The importance of the Corps' hydraulic structures has caused the Corps to move cautiously, but deliberately, toward exclusive use of strength design methods.

e. This manual modifies and expands the guidance in ETL 1110-2-312 with an approach similar to that of ACI 350R-89. The concrete stress-strain relationship and the yield strength of Grade 60 reinforcement given in ACI 318 are adopted. Also, the load factors bear a closer resemblance to ACI 318 and

are modified by a hydraulic factor,  $H_f$ , to account for the serviceability needs of hydraulic structures.

f. As in ETL 1110-2-312, this manual allows the use of a single load factor for both dead and live loads. In addition, the single load factor method is required when the loads on the structural component include reactions from a soil-structure stability analysis.

#### 1-5. General Requirements

Reinforced-concrete hydraulic structures should be designed with the strength design method in accordance with the current ACI 318, except as hereinafter specified. The notations used are the same as those used in the ACI 318 Code and Commentary, except those defined herein.

#### 1-6. Scope

a. This manual is written in sufficient detail to not only provide the designer with design procedures, but to also provide examples of their application. Also, derivations of the combined flexural and axial load equations are given to increase the designer's confidence and understanding.

b. General detailing requirements are presented in Chapter 2. Chapter 3 presents strength and serviceability requirements, including load factors and limits on flexural reinforcement. Design equations for members subjected to flexural and/or axial loads (including biaxial bending) are given in Chapter 4. Chapter 5 presents guidance for design for shear, including provisions for curved members and special straight members. The appendices include notation, equation derivations, and examples. The examples demonstrate: load-factor application, design of members subjected to combined flexural and axial loads, design for shear, development of an interaction diagram, and design of members subjected to biaxial bending.

#### 1-7. Computer Programs

Copies of computer programs, with documentation, for the analysis and design of reinforced-concrete hydraulic structures are available and may be obtained from the Engineering Computer Programs Library, US Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199. For design to account for combined flexural and axial loads, any procedure that is consistent with ACI 318 guidance is acceptable, as long as the load factor and reinforcement percentage guidance given in this manual is followed.

#### 1-8. Recission

Corps library computer program CSTR (X0066), based on ETL 1110-2-312, is replaced by computer program CASTR (X0067). Program CASTR is based on this new engineer manual.